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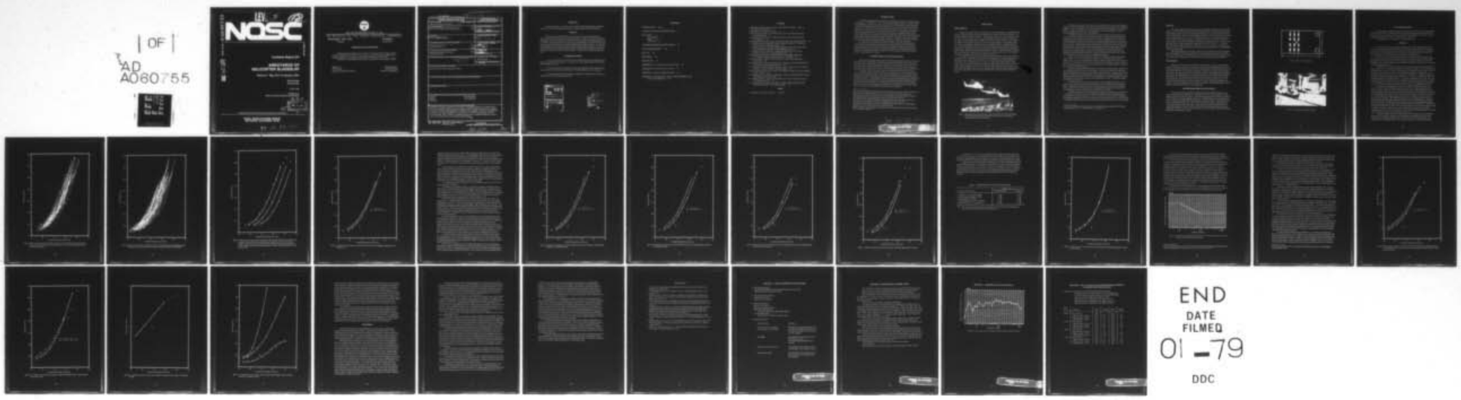

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ANNOYANCE OF HELICOPTER BLADESLAP

Research - May 1977 to February 1978

RG Klumpp
DR Schmidt

3 July 1978

Prepared for
Naval Facilities Engineering Command

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To determine the possible underassessment of annoyance by A-weighted measurements, 28 subjects rated the annoyance of helicopter sounds by a magnitude estimation method. The sounds were recorded in a residential community and included samples ranging from no bladeslap to heavy bladeslap. The degree of underassessment of annoyance by an average A-weighted measure was found to be 2 dB. This underassessment was found over the level range of 60 to 85 dB(A) for two different listener groups, for bladeslap classification by listeners or by crest factor measurement, and for simulated inside listening.

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OBJECTIVE

Determine whether a correction need be applied to helicopter average A-weighted sound levels to reflect accurately the annoyance created during bladeslap conditions.

RESULTS

Helicopter sounds with bladeslap were found to be more annoying than helicopter sounds without bladeslap when equated in terms of average A-weighted sound level. This higher annoyance was found for two different listener groups, for sound levels from 60 to 85 dB(A), for sounds with weak, moderate or heavy bladeslap, for sounds with high crest factors, and for spectra altered to simulate listening inside a typical residence. A correction of approximately 2 dB is indicated for the periods when bladeslap is present. The effect of this 2 dB correction on day-night average sound level (DNL) and on community noise equivalent level (CNEL) is less than 1 dB for bladeslap occurring 25% of helicopter operating time.

RECOMMENDATIONS

1. Use conventional noise monitoring systems employing average A-weighted sound levels for measuring helicopter noise. A correction of 2 dB is required only for the periods when bladeslap is present.

2. Examine closely the characteristics, other than bladeslap, which make some helicopter sounds extremely annoying while others of equal intensity are not as annoying.

3. Conduct experiments to determine the difference in annoyance between typical helicopter noise and fixed-wing aircraft noise.

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INTRODUCTION

It has been suggested that helicopter noise containing an impulse component, heard as "bladeslap" or "blade bang," may be more annoying than the annoyance predicted from the usual aircraft noise measurements. Corrections of up to 10 dB have been suggested to account for this potential annoyance underestimation. An interim correction of 7 dB was adopted at one Triservice conference[1] and has been endorsed by the FAA.[2] Evidence to support a correction has not been overwhelming. However, it is possible for A-weighted slow responding instruments to underassess helicopter noise containing strong, low frequency, high crest factor components. In land use planning, corrections as mentioned above would result in large changes in areas falling in critical noise impact zones; hence, the resolution of the problem of bladeslap penalty is important. This study and others published recently[3-5] represent an attempt to clarify the problem of bladeslap annoyance.

In many studies, the bladeslap problem is related to aircraft certification with measurements and recordings of the helicopter noise being made at relatively close distances. In the present study, the impetus is not certification but land use planning. Accordingly, recordings were made in a residential neighborhood of helicopters flying at a distance. The sound measurements are given in terms of average A-weighted levels taken over the sample length of 7 seconds.

CLASSIFICATION OF HELICOPTER NOISE

Helicopters are unique among aircraft in that they occasionally produce a distinctive impulsive sound. This impulsive component, often called bladeslap, is more easily recognized than defined. When this impulsive component is strong, instant and certain recognition occurs and a listener generally reports hearing a slap, crack, thud, or bang repeated cyclically at a rate of about five times a second. It has been suggested that as impulsive content of the sound increases, the degree of perceived bladeslap and annoyance increase.[3]

A number of measurement procedures have been proposed to assess the degree of impulsiveness in helicopter sounds. For example, emphasis has been placed upon impulse sound level, peak level in the octave band centered at 250 Hz, and crest factor as a ratio of A-weighted measures.[6] Although these measures have been proposed for use in certification procedures, it is not certain that they would be applicable to measure neighborhood helicopter sounds which typically occur at distances greater than those used for certification. Since questions exist about nonsubjective measures, the classification of helicopter sounds in this report will be by the judgement of two experienced listeners.

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[1] Joint-Service Air Installation Compatible Use Zone Noise Descriptor Conference, San Diego, CA, May 1975

[2] Federal Register, Volume 42, Number 2, Title 32, National Defense, Part 256.10, January 1977

[3] MAN-Acoustics and Noise, Inc, Noise Certification Considerations for Helicopters Based on Laboratory Investigations, Federal Aviation Administration report FFA-RD-76-116, July 1976

[4] James H Patterson, et al, Subjective Ratings of Annoyance Produced by Rotary-Wing Aircraft Noise, US Army Aeromedical Research Laboratory, USAARL Report No 77-12, May 1977

[5] Ben William Lawton, Subjective Assessment of Simulated Helicopter Blade-Slap Noise, NASA Langley Research Center, NASA Technical Note D-8359, December 1976

[6] William J Galloway, Physical Analysis of the Impulse Aspects of Helicopter Noise, FAA Contract, Report 3425, Project 09705, April 1977

PROCEDURE

NOISE SAMPLES

Most of the noise samples were obtained from recordings made in a residential neighborhood. Tape recordings of helicopter flights were made over a several week period – as the opportunities presented themselves. The majority of flights were at an altitude of about 125 metres (410 feet) above sea level; the microphone was located about 45 metres (150 feet) above sea level. Slant ranges of 400 metres (1300 feet) were common; slant ranges of over 800 metres (2600 feet) occurred in some of the noise samples. The majority of helicopters were in straight line flight but some were turning, banking, or changing altitude. The range of flight sounds was from the prominent bladeslap noise to only the usual engine and gear noise. Most of the sounds recorded were produced by Bell AH-1J, Kaman SH-2, Sikorsky SH-3, and Boeing Vertol CH-46 helicopters. Figure 1 shows three types of helicopters recorded in this experiment. Nearly all of the recorded samples were from individual helicopters, although occasionally two or three were present.

Recordings were made using wideband recorders operated in such a manner that no clipping occurred. Appendix A gives details of this equipment. The neighborhood recording procedure gave a wide variety of helicopter sounds that impact upon a residential community. The recordings also gave a variety of nonhelicopter neighborhood sounds – many occurring simultaneously with the helicopter sound. Only those samples free of car, children, dog, and other aircraft sounds were used. Since bird sounds were present in so many of the recordings it was necessary to include some in order to obtain enough samples for testing. Bird sounds were evenly distributed between bladeslap and non-bladeslap noises.

Figure 1. Photograph of three Navy helicopters: SH-2 (left), SH-3 (center), and CH-46 (right). Most of the sounds used in the present study came from these three types, and from the Marine Corps AH-1J helicopters.

Helicopter noise samples were selected from several hours of recordings. Whenever possible, a sample of bladeslap and a sample of non-bladeslap noise from the same flight were included. A set of 70 samples, 35 with bladeslap and 35 without bladeslap, was assembled. Of the 35 samples with bladeslap, 15 were judged to have heavy bladeslap, 11 to have moderate bladeslap, and 9 to have weak bladeslap.

A method of magnitude estimation was chosen for this experiment because of its efficiency in processing large numbers of noise samples.[7] Preliminary tests indicated the composition of the standard sound to which the listeners would reference the helicopter sounds substantially affected the difficulty of the task of judging annoyance. Listeners reported difficulty in judging annoyance when the standard sound was a noise band, whether narrow or wide. Of the nonlaboratory sounds tried as a standard, the sound of a large city bus shifting gears while climbing a slight grade was preferred. This sound appeared to be a good choice as a standard since it was deemed familiar to all potential listeners, had a frequency and energy distribution similar to that of helicopter sounds, had little of the emotional connotations of jet aircraft noise, and lent itself nicely to the concept of judging the annoyance of familiar sounds in a neighborhood context.

Once selected from the original recordings, the 70 helicopter samples were duplicated on tape, cut to a 7 second duration with a 0.5 second rise/fall time to minimize sudden onset effects and combined with 7 duplicates of the standard bus sound to form the nucleus of a test sequence. The 70 helicopter sounds were randomized in order, separated by 3 seconds of silence (blank tape), and combined with seven standard sounds, one preceding each block of 10 helicopter noises.

This tape was then duplicated with the level of each helicopter sample randomly set to five different levels by means of an attenuator. The five sound levels were 6 dB apart and permitted playback presentation of samples at sound levels over a range from about 50 dB(A) to 90 dB(A). The standard sound was recorded at a constant level throughout. The end product of this effort was a 385 item test consisting of 35 standard sounds, one preceding each block of 10 helicopter sounds, and 350 helicopter sounds – 70 different samples each at five different levels.

Care was exercised to keep from changing the peak to RMS level difference of the samples in the original recording and in the first and second duplication by using conservative recording levels. Before and after comparisons showed no loss in peak to RMS difference. Because of this cautious approach, unavoidable reductions of a few decibels in overall signal-to-noise of the helicopter noise samples were produced.

During preliminary tests it was decided that samples of helicopter noise lasting about 7 seconds were long enough to make a judgement of bladeslap and non-bladeslap annoyance generated by a longer sample, say a 30 second flyby. It was felt that for a bladeslap/non-bladeslap comparison most of the annoyance would be produced by the loudest portion of a flight and that the loudest portion would be adequately presented by a 7 second sample.

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[7] Karl D Dryter, Prediction of Paired-Comparison and Magnitude-Estimation Judgements of Noisiness, Sensation Measurement, p 275-283, HR Moskowitz, et al (ed) 1974

SUBJECTS

Two different groups of listeners were used. One group consisted of 19 people who worked at a Navy laboratory and who were persuaded to serve as listeners for an afternoon. The age range was from 21 to 52 years with a mean age of 36.7 years. Fourteen were men and five were women. Most had normal hearing sensitivity but two of the men had moderate to severe high frequency losses. The second group consisted of nine college students, ages 19 to 27 years with a mean age of 22.5. The four men and five women had essentially normal hearing – from 500 to 8000 Hz as determined by audiometric testing. All were paid volunteers with no unique attitudes or experiences related to helicopter or aircraft noise. All of the student group and most of the laboratory group had little previous exposure to helicopter noise. A few of the laboratory people had extensive experience in measuring helicopter and aircraft noise.

The student group was tested first. All nine served as listeners in annoyance judgement tests during four consecutive afternoons. Five of the nine also served in annoyance tests on two afternoons of the following week. In the laboratory group seven people served in a session on one afternoon and 12 people served in a session on a second afternoon.

TEST SESSION

In the first test session for each group, a 50 item practice tape was used to familiarize the listener with the annoyance judgement procedure. The instructions given to the listeners are printed as Appendix B. In effect, the instructions requested the listeners to rate each of 350 helicopter noise samples in annoyance with respect to the bus noise standard sound which was played before each 10 helicopter samples. The standard sound was assigned a value of 100 and sounds twice as annoying were to be rated at 200, half as annoying at 50, and so on. After the practice period and a brief discussion period, the test of 385 items was begun. Presentation levels were set acoustically before each test session. The entire test of 350 helicopter and 35 bus samples was run in four blocks separated by rest periods. Each block required about 17 minutes to complete. The total test session of 2-1/2 hours included about 67 minutes of active listening.

LOUDSPEAKER PRESENTATION SYSTEM

Noise samples were presented via a high quality, broadband loudspeaker system whose details are given in Appendix A. Appendix C shows the acoustic response of this playback system to a pink noise input. The loudspeaker presentation system was operated so as to ensure that no peak clipping would occur. The playback system was operated in a quiet, 10 foot–6 inch high studio whose plan view is shown in figure 2. The listeners were seated in chairs indicated in black. "X" marks the position of the microphone used for much of the analysis of the noise samples. This analysis microphone was positioned at seated head height by means of a tripod. One-third octave band analysis of a pink noise signal indicated that levels were quite similar from one seat to another. Figure 3 shows the listeners in a simulated test session.

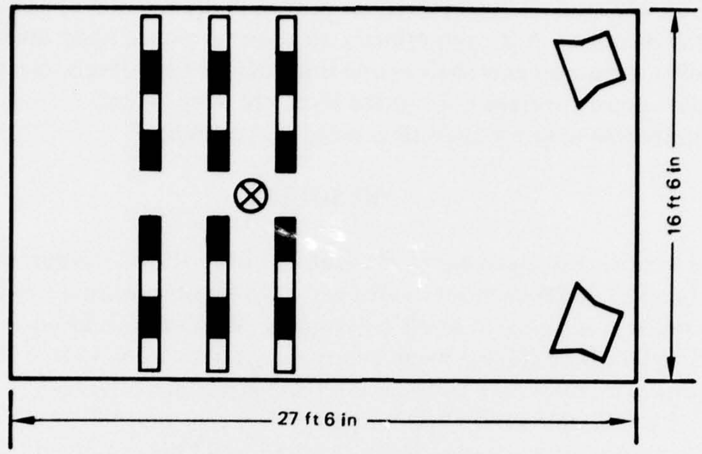

Figure 2. Plan view of testing studio.

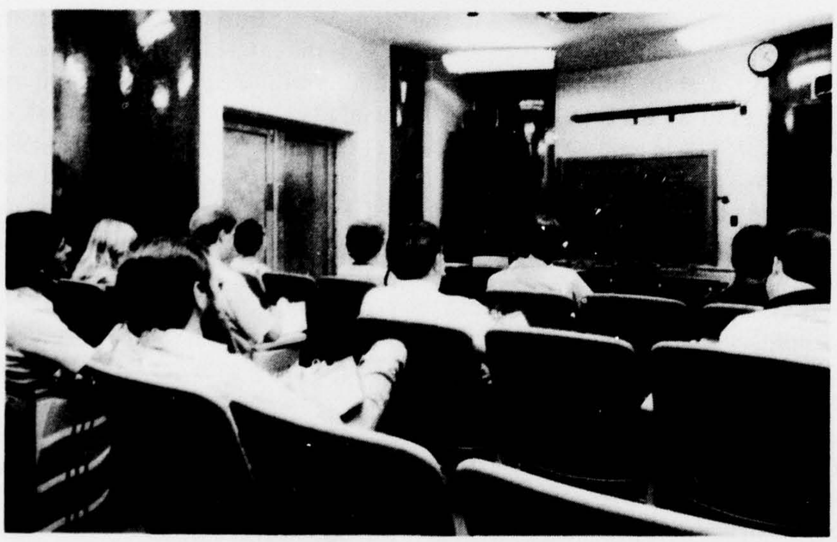

Figure 3. Listeners in a simulated test session.

ANALYSIS PROCEDURE

All of the physical analysis presented in this report is based upon the acoustic signal presented to the listeners. Although primary emphasis is placed upon average A-weighted sound level, other measurements such as one-third octave band levels, crest factor as a ratio of A-weighted measures, average C-weighted level, etc were taken.

The equipment used for analysis is listed in Appendix A.

RESULTS

Figure 4 shows the mean annoyance rating of the 19 Navy laboratory listeners to each of 35 helicopter noises without bladeslap. Each line connecting five points represents a noise presented at five different levels 6 dB apart. Noises in this group were presented at levels from 55 to 92 dB producing mean annoyance ratings from 45 to 670. Clearly, the annoyance rating was a function of noise level and noise characteristic.

Figure 5 is the same kind of plot as figure 4 except that the 35 noises rated were with bladeslap and were presented at levels from 51 to 92 dB. Generally speaking, figure 4 and figure 5 show the same results. Similar annoyance ratings were given to noises with bladeslap as noises without bladeslap when both were equated on the basis of the commonly used A-weighted average level.

Comparing the annoyance ratings of noises in figure 4 with the annoyance ratings in figure 5 is not easy. Accordingly, simplification of figure 4 and figure 5 was sought through averaging. Figure 6 shows the effect of grouping and averaging the data of figure 4. The set of points to the left shows the effects of grouping and averaging in 3 dB intervals, eg, all annoyance ratings for the noises in the interval from 54.5 dB to 57.5 dB were averaged and plotted at 56 dB. All annoyance ratings for noises in the interval 57.5 dB to 60.5 dB were averaged and plotted at 59 dB, and so on. The number of judgements per point varies. For example, the point at 56 dB is based on 152 judgements (19 listeners x 8 noises), at 59 dB on 171 judgements (19 listeners x 9 noises), and at 62 dB on 323 judgements (19 listeners x 17 noises). If the less stable end points are ignored, a curve can easily be fitted visually.

Grouping and averaging was also done on a 4 dB and a 5 dB basis to find out whether the size of the interval had any great influence on the shape and location of the curves generated. The center set of points in figure 6 and the curve fitting them are the result of 4 dB grouping and averaging while the points and curve to the right are the product of 5 dB grouping and averaging. For convenience in comparing the three curves generated by the 3 dB, 4 dB, and 5 dB groupings, the 3 dB points are plotted at levels as they are presented to the listeners. The 4 dB grouping points have had 5 dB added to their levels before plotting and the 5 dB grouping point levels have had 10 dB added before plotting. Had not the 5 and 10 dB displacements been made, the three curves would have fallen on top of one another. As can be seen, three parallel curves can be easily fitted – each one separated from its neighbor by 5 dB. The size of the grouping interval did not change the shape or location of the curve describing the relationship between annoyance rating and A-weighted average level. With no advantage to any of the three grouping intervals the middle interval, 4 dB, was chosen for use in further comparisons.

Using the 4 dB grouping and averaging process on the data of figure 4 and figure 5 allows a more convenient comparison of the annoyance ratings given to the helicopter noises with and without bladeslap. Figure 7 shows the two sets of points (dot = non-bladeslap and x = bladeslap) and the curve fitted to each set. A consistent difference is

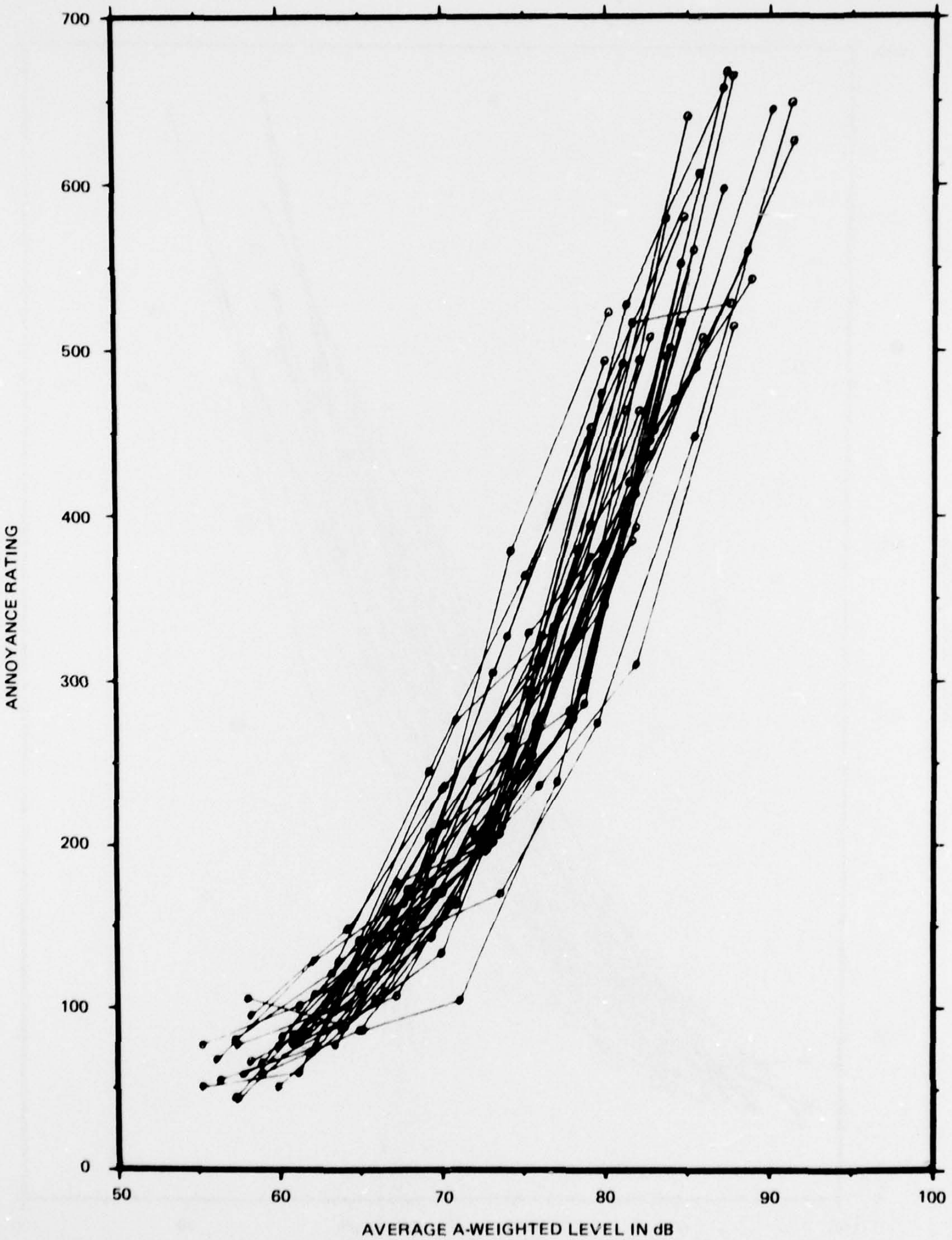

Figure 4. Mean annoyance ratings by 19 laboratory listeners of 35 helicopter sounds without bladeslap. Each of the sounds represented by a line was presented at the five average A-weighted sound levels shown by the dots.

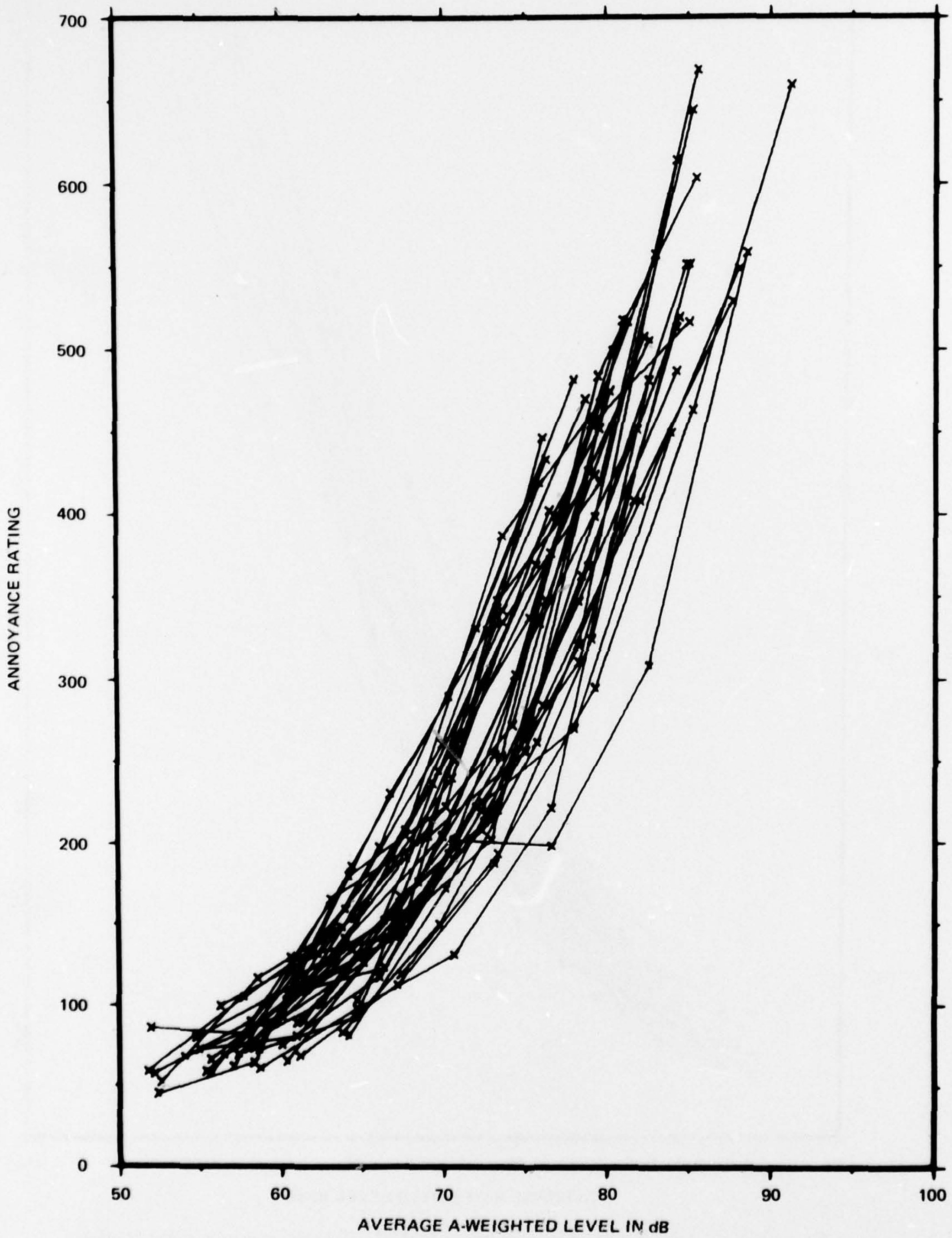

Figure 5. Mean annoyance ratings by 19 laboratory listeners of 35 helicopter sounds with bladeslap. Each line represents one sound presented at five average A-weighted sound levels, 6 decibels apart.

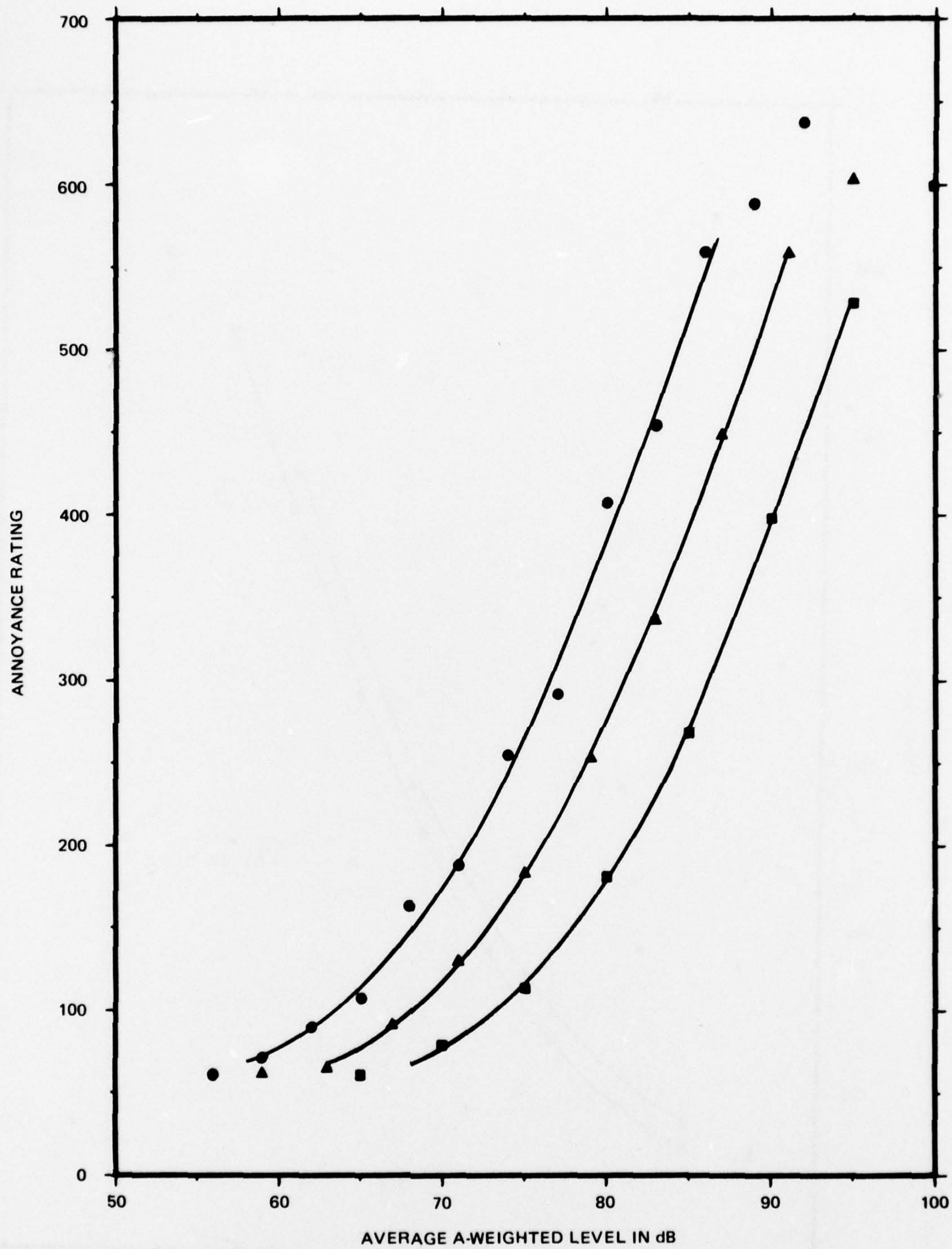

Figure 6. Mean annoyance ratings of figure 4 grouped in 3 dB, 4 dB, and 5 dB intervals. Circles represent grouping in 3 dB intervals with the mean annoyance rating plotted at the interval midpoint. Triangles represent the same data grouped into 4 dB intervals and 5 dB has been added before plotting. Squares represent the same data grouped into 5 dB intervals and 10 dB has been added before plotting.

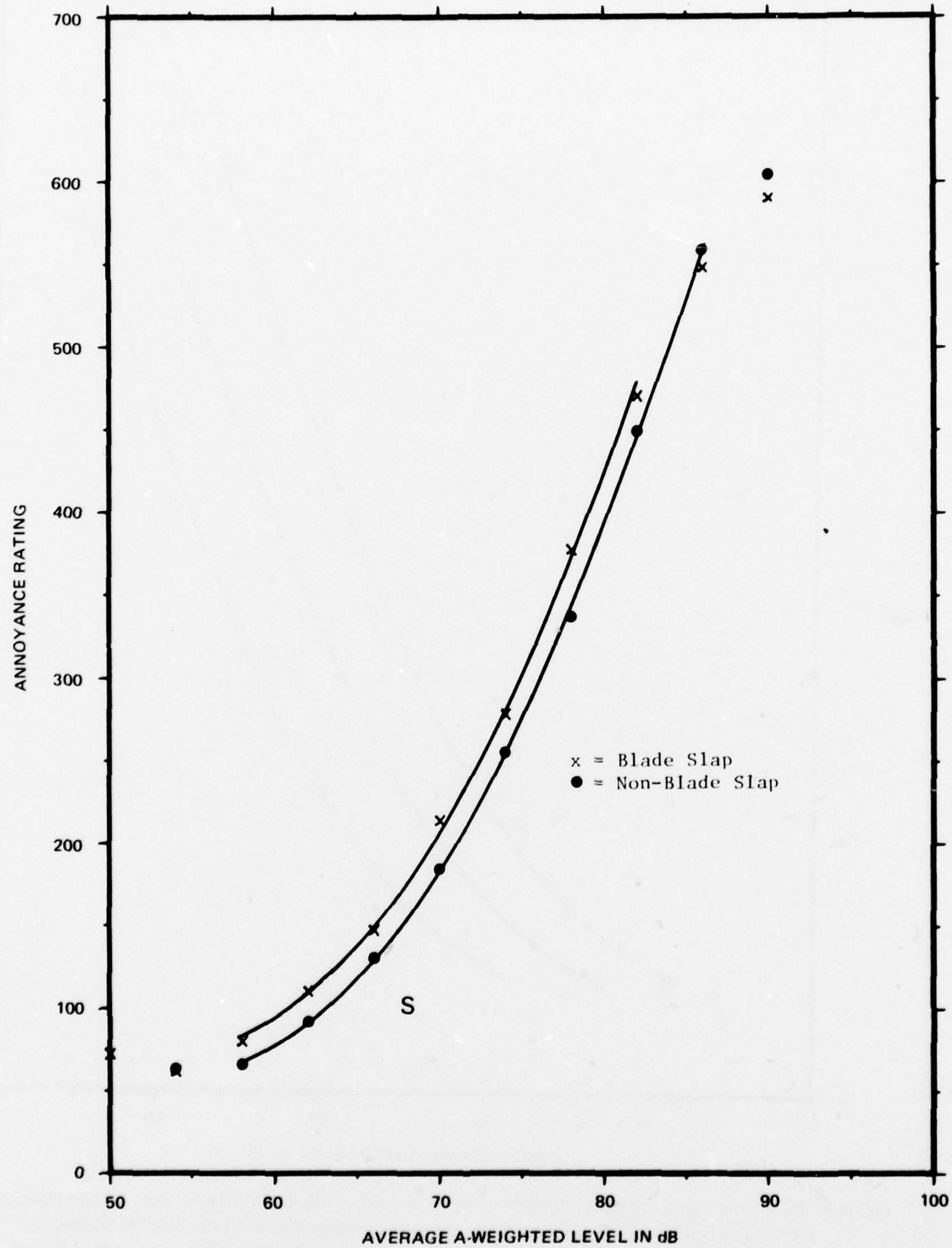

Figure 7. Comparison of mean annoyance ratings of laboratory group of 35 bladeslap sounds with 35 non-bladeslap sounds.

evident between the two sets of points. Mean annoyance ratings for the 35 sounds with bladeslap are greater than those for the 35 non-bladeslap sounds. When an annoyance rating is chosen which intersects the bladeslap and non-bladeslap curves at a level of about 70 dB(A), the difference between the curves is found to be 1.4 dB. This will be called the level difference between bladeslap and non-bladeslap. The letter "S" in figure 7 and the following response plots indicate the average level and assigned annoyance rating of the standard sound.

In this experiment the difference between the group of 35 sounds with bladeslap and 35 without bladeslap depends on how well the sounds were initially classified. To detect any differences which may have been obscured by incorrect classification, a more rigorous selection of bladeslap noise was made. From the group of 35 bladeslap noises only those sounds which could be described as having moderate or heavy bladeslap were selected. Figure 8 shows the comparison of the judged annoyance of these 26 sounds with the original group of 35 non-bladeslap sounds. The effect of the removal of the nine weak bladeslap sounds was to increase the level difference from 1.4 to 2.0 dB.

An additional comparison using only 15 of the bladeslap sounds, those with "heavy" bladeslap, is given in figure 9.

The differences obtained in figures 7, 8 and 9 are consistent and suggest that the general effect of eliminating the less strong bladeslap samples from the comparison is to increase the annoyance of the bladeslap group slightly. Thus, the mean annoyance rating for the 70 dB(A) level of all 35 bladeslap noises was 210; for the 70 dB(A) level of 26 moderate/heavy bladeslap noises it was 215; and for the 70 dB(A) level of 15 bladeslap sounds 225. The level difference shows a change from 1.4 dB to 2.0 dB to 2.2 dB.

Some of the helicopters flew past the recording microphone at such angles that during part of the flight bladeslap noise was present and during another part of the flight no bladeslap was present. A noise sample containing bladeslap and a noise sample without bladeslap were taken from each of nine such flights. Figure 10 shows a pair of curves – the curve fitting the solid dots representing the mean of annoyance ratings of the non-bladeslap samples and the curve fitting crosses representing the ratings of nine bladeslap samples. The level difference between the bladeslap and non-bladeslap curves taken at a sound level around 70 dB(A) is 2.2 dB with the mean bladeslap responses showing a higher annoyance as in previous comparisons.

To check that the procedure of aural classification of the 70 sounds was not somehow biasing the comparisons, a measure of crest factor as advocated by Galloway[6] for processing helicopter sounds was used to select new subgroups for comparison. The difference between peak A-weighted and slow A-weighted levels was determined for all noises. Thirteen noises with a mean crest factor equal to or greater than 15 dB were selected. An additional set of 13 noises with a mean crest factor of 12.5 or less was selected for comparison. Averaged points for these high and low crest factor sets are shown in figure 11 with the high crest factor plotted with triangles and the low crest factor plotted with squares. As before, the mean annoyance rating is plotted as a function of A-weighted average level.

Listeners rated the annoyance of the high crest factor sounds greater than that of the low crest factor sounds. The level difference was found to be 2.5 dB. Thus, whether the categorization is on the amount of bladeslap judged by ear or on the size of crest factor as measured by instrument, the level difference of different categories of helicopter sounds remains essentially the same.

This is not too surprising when the relationship between crest factor and judged bladeslap is considered. Of the group of 13 noises with crest factors of 15 and over, seven came from the "heavy" bladeslap group and six came from the "moderate" bladeslap group. Of the comparison group with low crest factors, all 13 came from the non-bladeslap group.

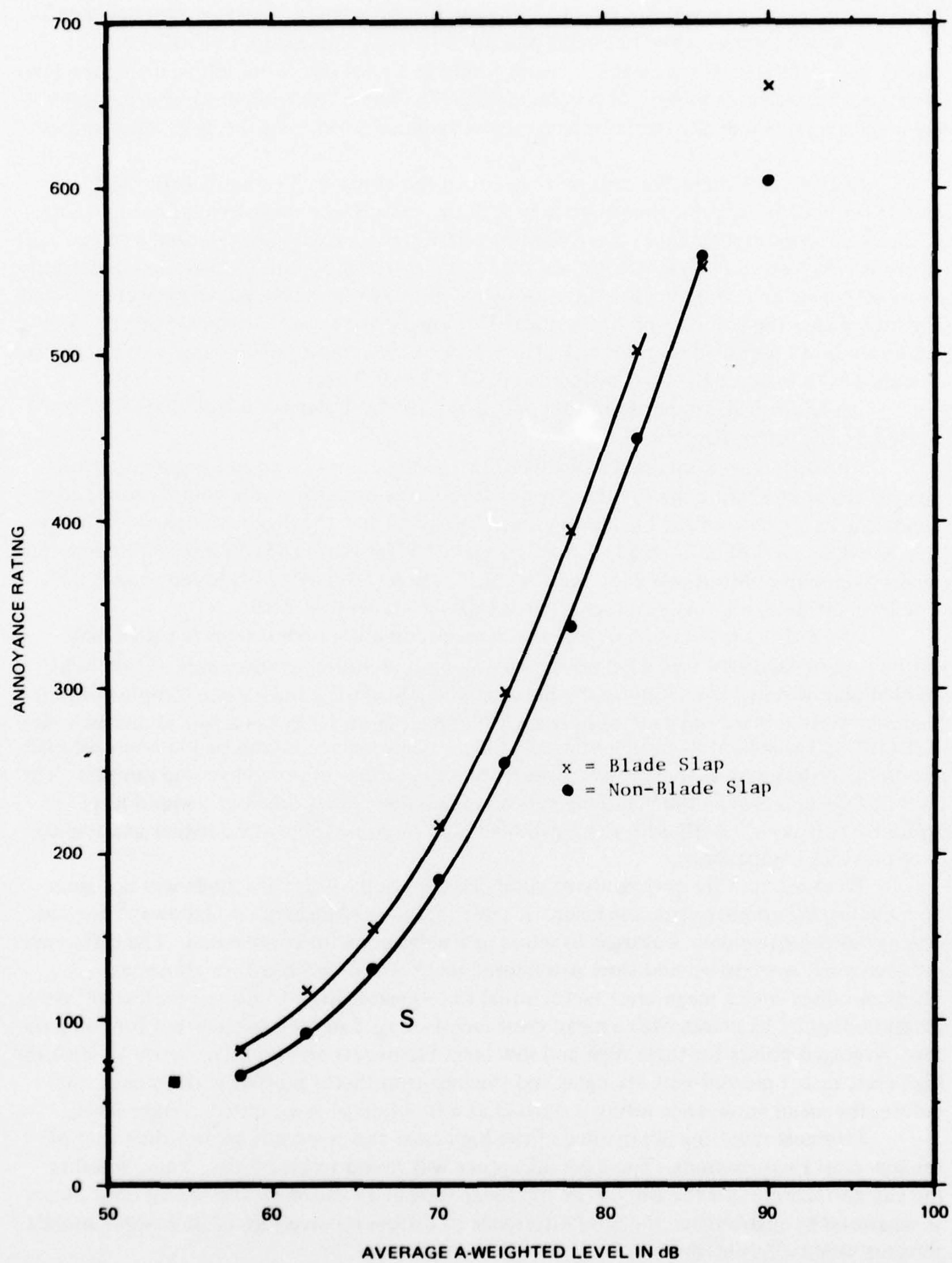

Figure 8. Comparison of mean annoyance ratings of laboratory group of 26 moderate to heavy bladeslap sounds with 35 non-bladeslap sounds.

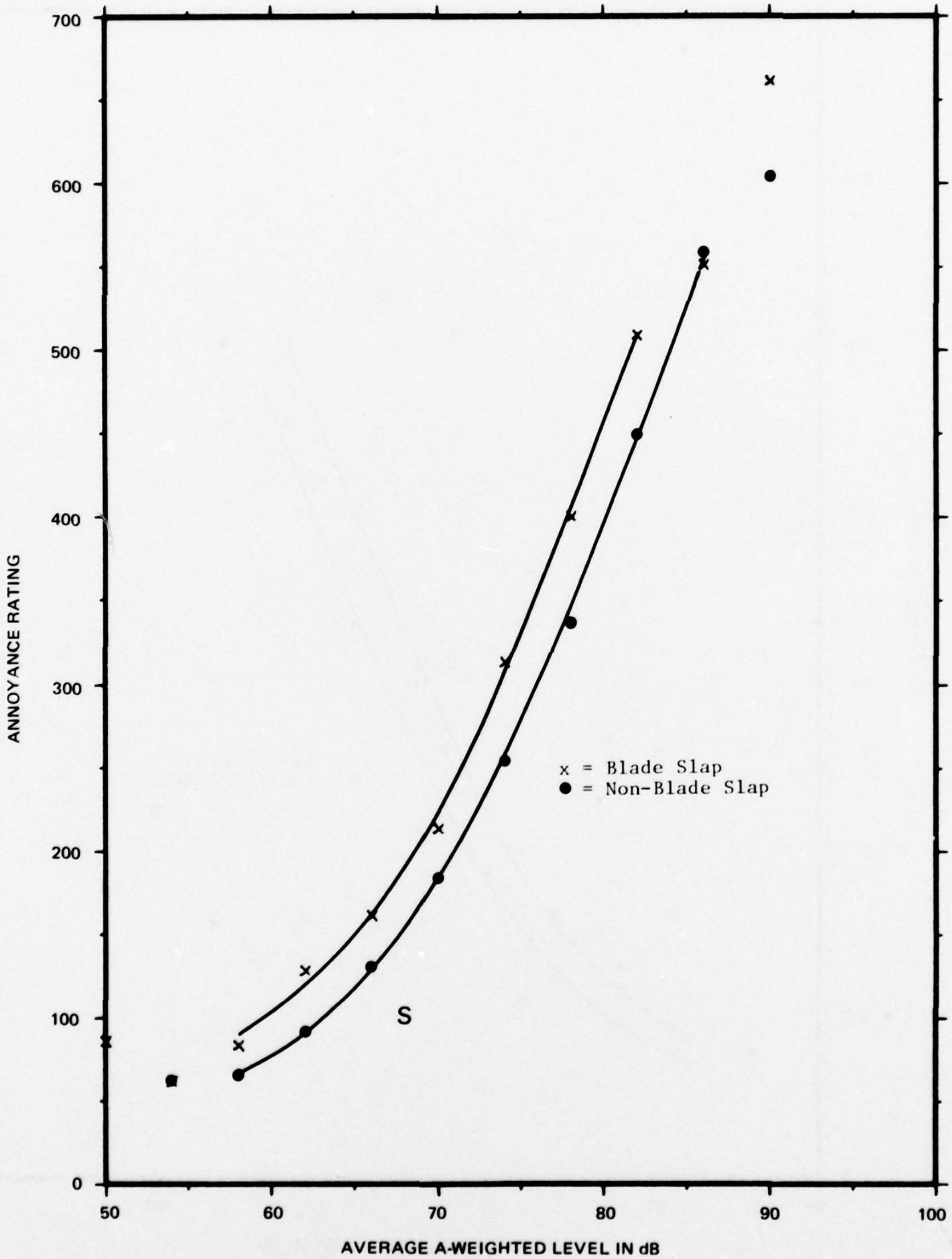

Figure 9. Comparison of mean annoyance ratings of laboratory group of 15 heavy bladeslap sounds with 35 non-bladeslap sounds.

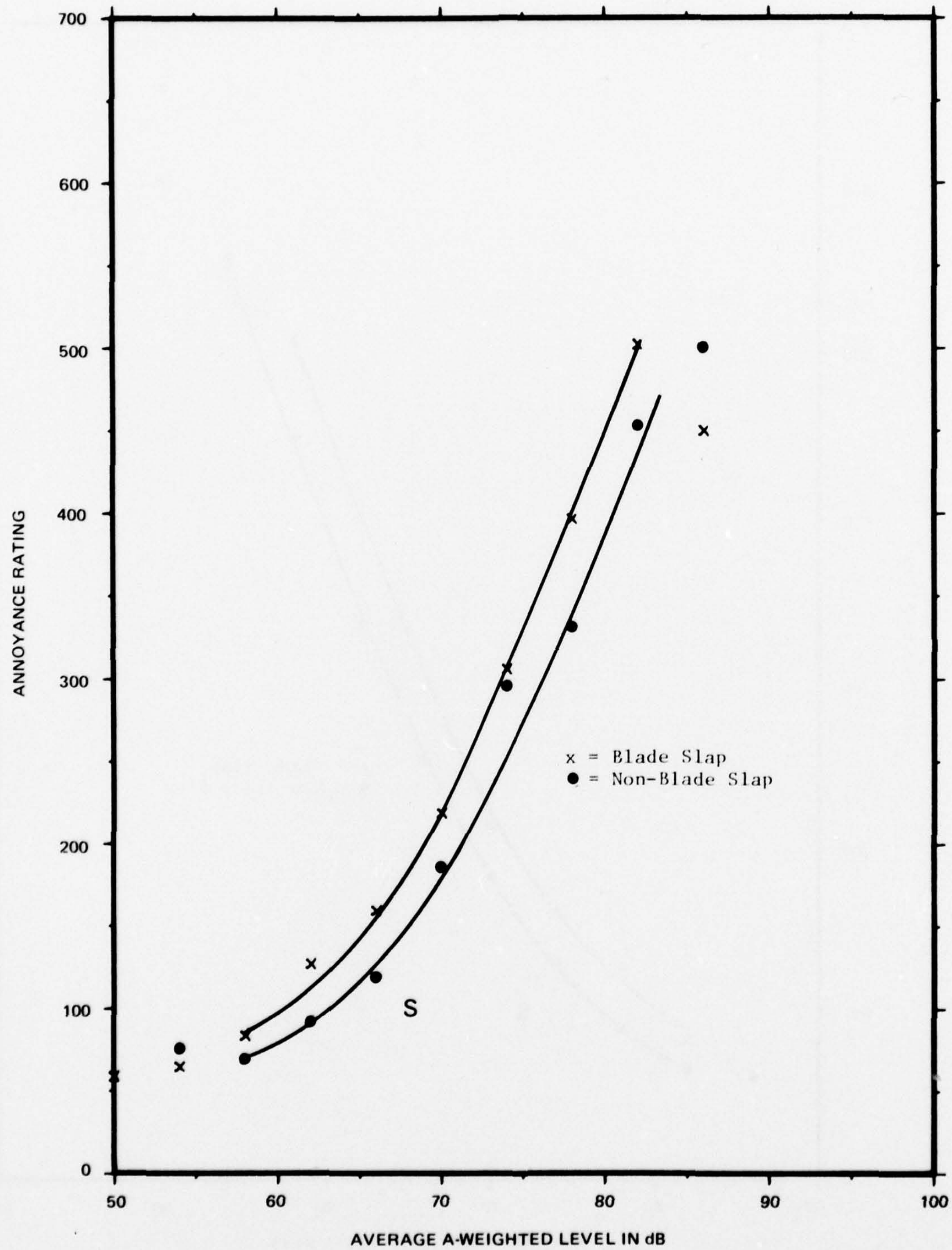

Figure 10. Mean annoyance ratings of laboratory group of 9 bladeslap sounds with 9 non-bladeslap sounds occurring during the same flight.

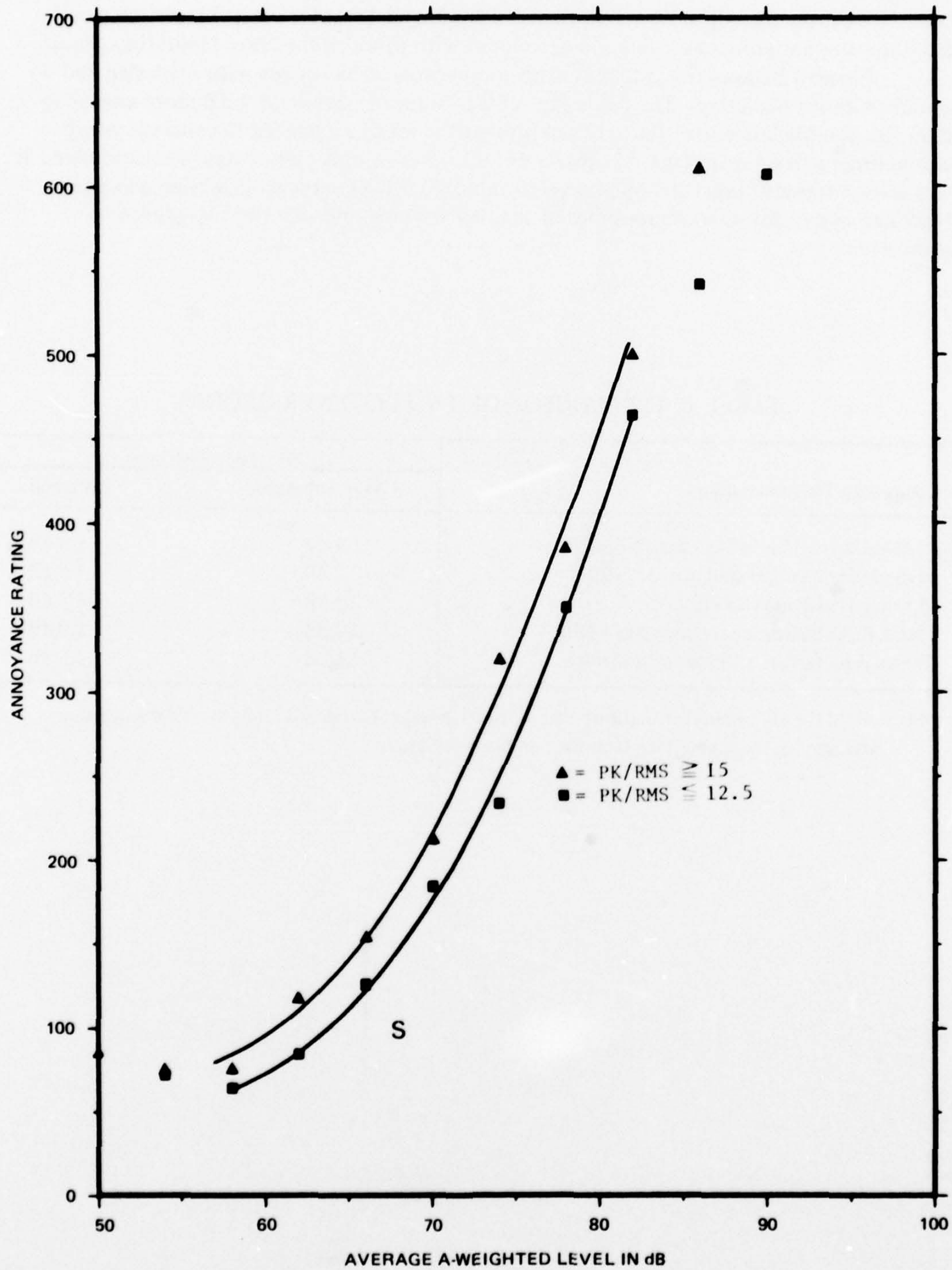

Figure 11. Mean annoyance ratings of laboratory group of sounds with high and low crest factors.

In addition to the 19 person Navy laboratory group, nine students rated the helicopter noises for annoyance. Results obtained with this younger, more normal hearing, less noise exposed group are given in figures 12, 14, and 15. In most instances the results from the student group were in good agreement with those of the Navy laboratory group.

Figure 12 shows the student group comparison of 35 sounds with bladeslap and 35 sounds without bladeslap. The bladeslap set was judged to be about 1 dB more annoying than the non-bladeslap set. Rather than present the set of graphs for the student group comparing the level difference of subsets of helicopter sounds table 1 has been compiled. It lists level difference taken at sound levels around 70 dB(A) between bladeslap and non-bladeslap curves for various groupings of the helicopter sounds for the two groups of listeners.

TABLE 1. COMPARISON OF TWO LISTENER GROUPS.

Comparison Noise Groupings	"Outside" Listeners	
	19 Navy Laboratory	9 Students
35 bladeslap vs 35 non-bladeslap (NBS)	1.4 dB	1.0 dB
26 moderate/heavy bladeslap vs 35 NBS	2.0 dB	1.5 dB
15 heavy bladeslap vs 35 NBS	2.2 dB	1.2 dB
9 same flight bladeslap vs 9 same flight NBS	2.2 dB	1.0 dB
13 high crest factor vs 13 low crest factor	2.5 dB	2.5 dB

Note: All of the above numbers indicate that at equal average A-weighted levels the bladeslap group was rated as more annoying than the non-bladeslap group.

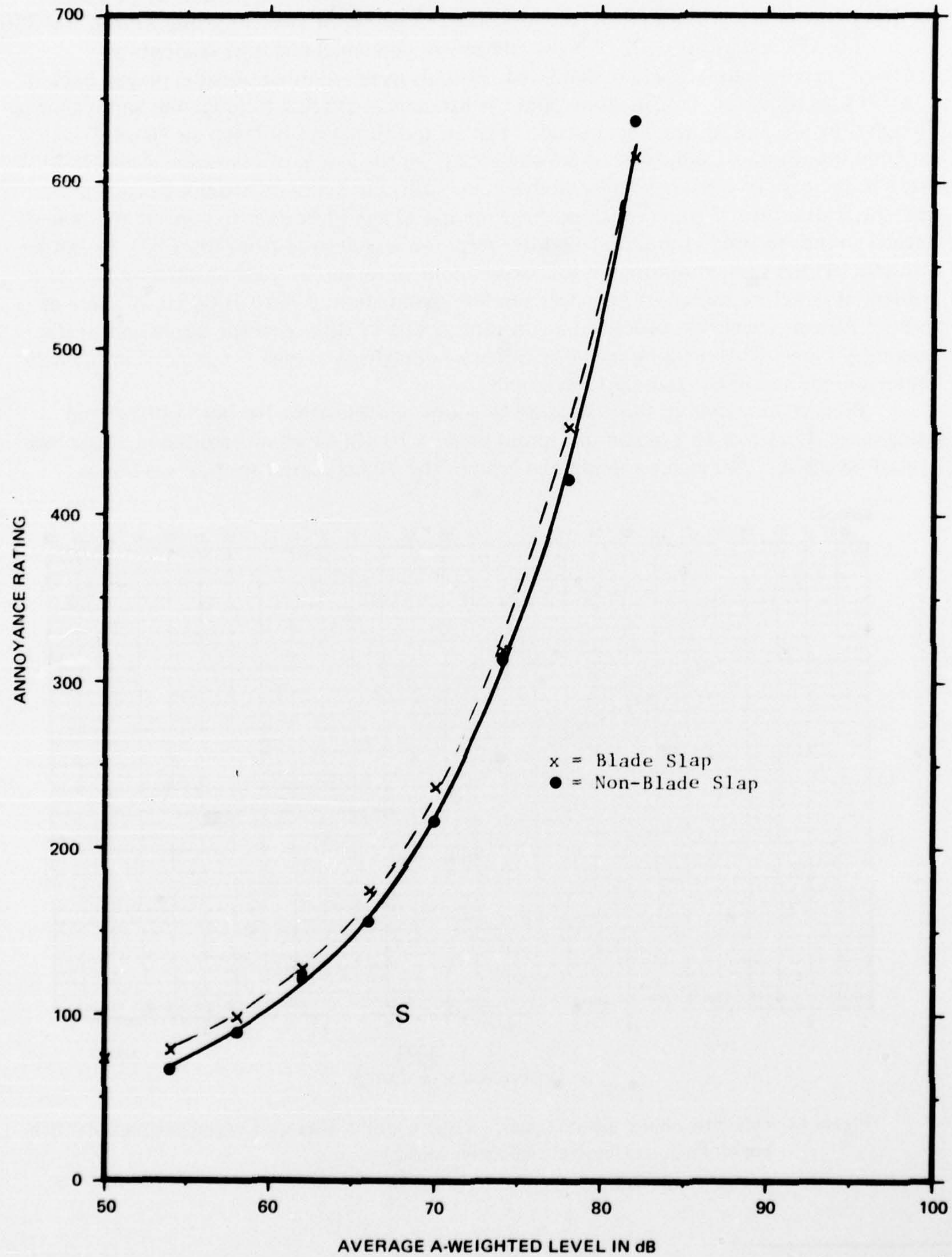

Figure 12. Mean annoyance ratings of 9 students of 35 helicopter sounds with bladeslap and 35 sounds without bladeslap.

The student group assigned larger annoyance ratings to all the helicopter sounds than did the Navy laboratory group. Typically, for the 26 bladeslap sounds at 70 dB(A), the Navy laboratory group's mean response was 215 while the student group's mean was 250.

For the main tests with 19 Navy laboratory personnel and nine students an "outside" listening situation was simulated. Sounds were recorded outside, played back in a studio with minimum modification, and the listeners instructed to judge the annoyance as though they and the source were outside. For an additional set of tests, an "inside" listening situation was simulated. Five students from the group of nine were available to listen to the tape of outside sounds modified by a filter to simulate listening inside a residential structure. Figure 13 shows the response of the filter used to convert the tape of outside sounds to inside sounds. This filter response was derived from Bishop.[8] As can be seen (fig 13) the simulation used in this experiment to represent the transmission loss of a residential structure rolled off the spectrum level from about 100 to 1000 Hz at a rate of about 3 dB per octave and produced a constant loss of 12 dB across the upper end of the frequency band. This filtering was discernible as a muffling of high frequencies in the helicopter sounds and in the standard bus sound.

Presentation level of the standard bus sound was the same for both outside and inside tests. It was set to a maximum sound level of 70 dB(A) which resulted in an average level of 68 dB(A). For inside sounds, the level of the 70 helicopter sounds was less as

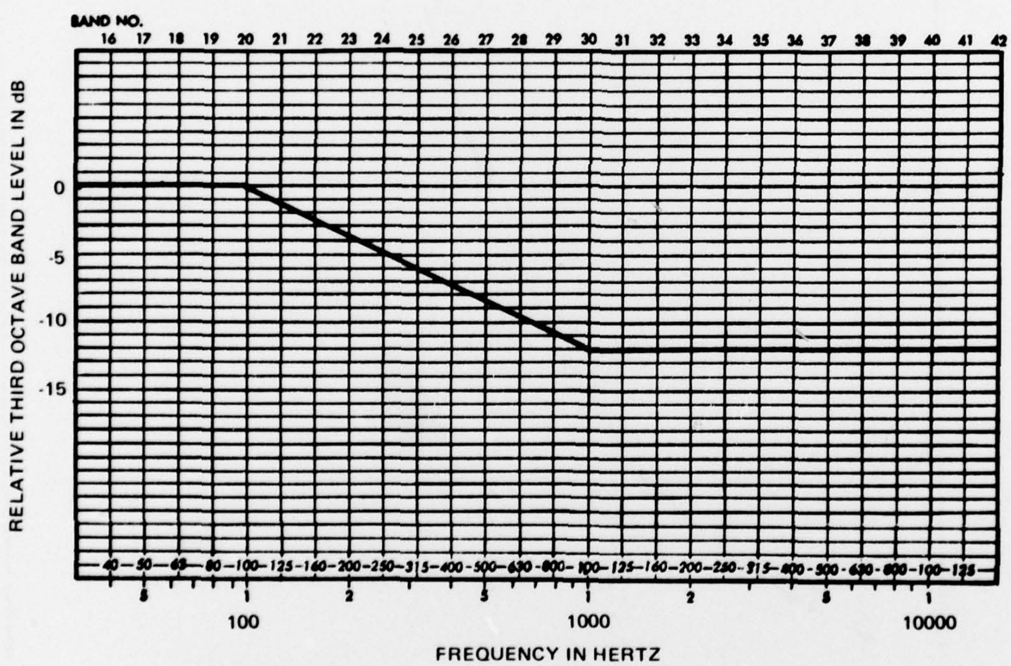

Figure 13. One-third octave band frequency response of the filter used to convert "outside" helicopter sounds to "inside" helicopter sounds.

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[8]Dwight E Bishop, Reduction of Aircraft Noise Measured in Several School, Motel and Residential Rooms, Journal of Acoustical Society of America, vol 39, no 5, Part 1, 1966, p 907-913.

measured by an average A-weighted level. The mean of the inside helicopter sounds was 6 dB less than the outside noise mean with a range of difference among the 70 sounds from 0.7 to 7.3 dB. It should be noted that this inside test did not try to simulate inside listening levels but only the frequency modification produced by a residence.

Listeners who served in the inside tests were told what was done to the outside sounds to convert them to inside sounds. They were told the only change in their judgement procedure was to judge the annoyance as if they were inside their homes.

Figure 14 shows the relationship of the judged annoyance of 35 bladeslap sounds and 35 non-bladeslap sounds for the simulated inside listening condition. Bladeslap response means are plotted with Xs and non-bladeslap response means with dots. A level difference of 2.0 dB is seen between the two conditions around 70 dB(A). The suppression of high frequency components in the helicopter noise increased the level difference between bladeslap and non-bladeslap noise when compared to outside ratings. A level difference of 2.5 dB was found for the 26 moderate/heavy bladeslap group versus the 35 non-bladeslap sounds. For the 15 heavy bladeslap group as compared with the 35 non-bladeslap group, a level difference of 1.5 dB was found.

Filtering to simulate inside listening also altered the magnitude of the annoyance judgements. This can be seen in figure 15 for the five students participating. The figure compares 35 bladeslap noises inside with the same 35 bladeslap noises outside. At equivalent sound levels up to about 75 dB(A), the inside noises were rated more annoying than the outside noises. Translated to a level difference it would be about 2 dB. There is a crossover about 77 dB(A). At sound levels higher than 77 dB(A) the outside noises were more annoying than the inside noises.

Often, annoyance rating judgements are converted to a logarithmic form for display. This is done in figure 16 for the laboratory listeners judging 35 bladeslap noises. This graph is a log form of the bladeslap information presented in figure 7. A straight line provides a good fit to the points in figure 16 except at the highest sound levels. An examination of the slope of the line in figure 16 shows a doubling of annoyance for every 9 dB increase in noise level. This is a little less than the 7 dB reported by Patterson, et al[5] but agrees with the 9 dB relation given by Stevens as a general rule for perceived magnitude.[9]

The standard bus sound was presented at a average A-weighted level of 68 dB. Helicopter sounds were presented at A-weighted average levels from 51 to 92 dB with 41 percent of the sounds at or below the level of the standard. An examination of figure 7 through 12 shows that all but a few helicopter sounds were rated as more annoying than the standard by both the laboratory and student groups. It appears that the bus sound would have to be increased in level by about 6 dB to be as annoying as helicopter sounds for the laboratory group, and increased by about 9 dB to be as annoying as helicopter sounds for the student group. This assumes the bus annoyance would follow the same relationship with level as the helicopter sounds.

To find out how individual listeners differed, a set of points representing each listener's annoyance rating of all 70 helicopter noise samples was obtained using the 4 dB grouping and averaging procedure. Figure 17 shows averaged responses and visually fitted curves as a function of average A-weighted level of the responses of three of the listeners – people with the highest, median, and lowest ratings at 70 dB(A). The curve to the left, representing the listener assigning the highest annoyance ratings had a slope of about 40

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[9]SS Stevens, Assessment of Noise – Calculation Procedure Mark VII, Laboratory of Psychophysics, Harvard University, 1969

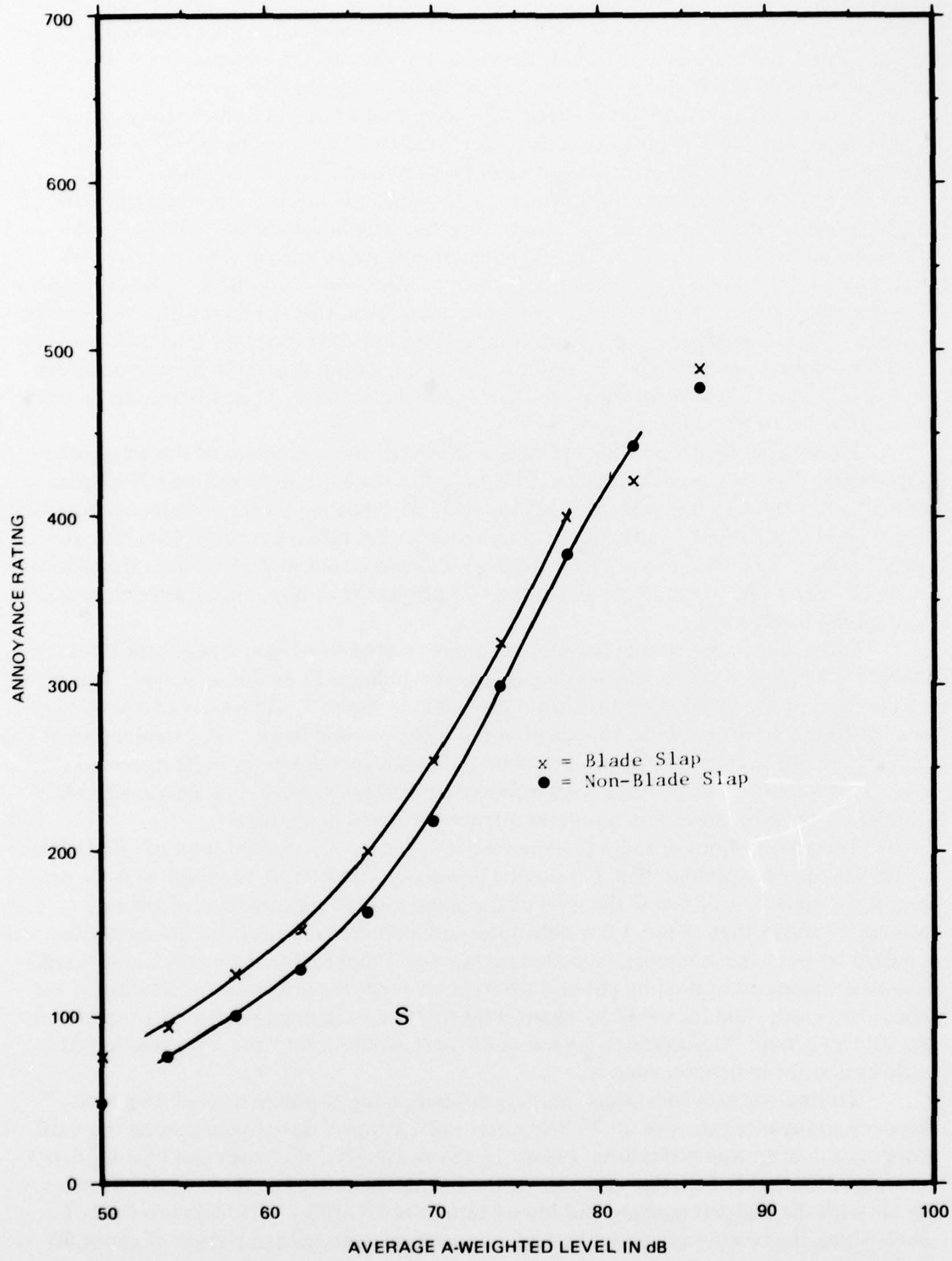

Figure 14. Mean annoyance ratings of 5 students of 35 helicopter sounds with bladeslap sounds and 35 non-bladeslap "inside" sounds. All 70 sounds were tailored by a filter to simulate "inside" listening conditions.

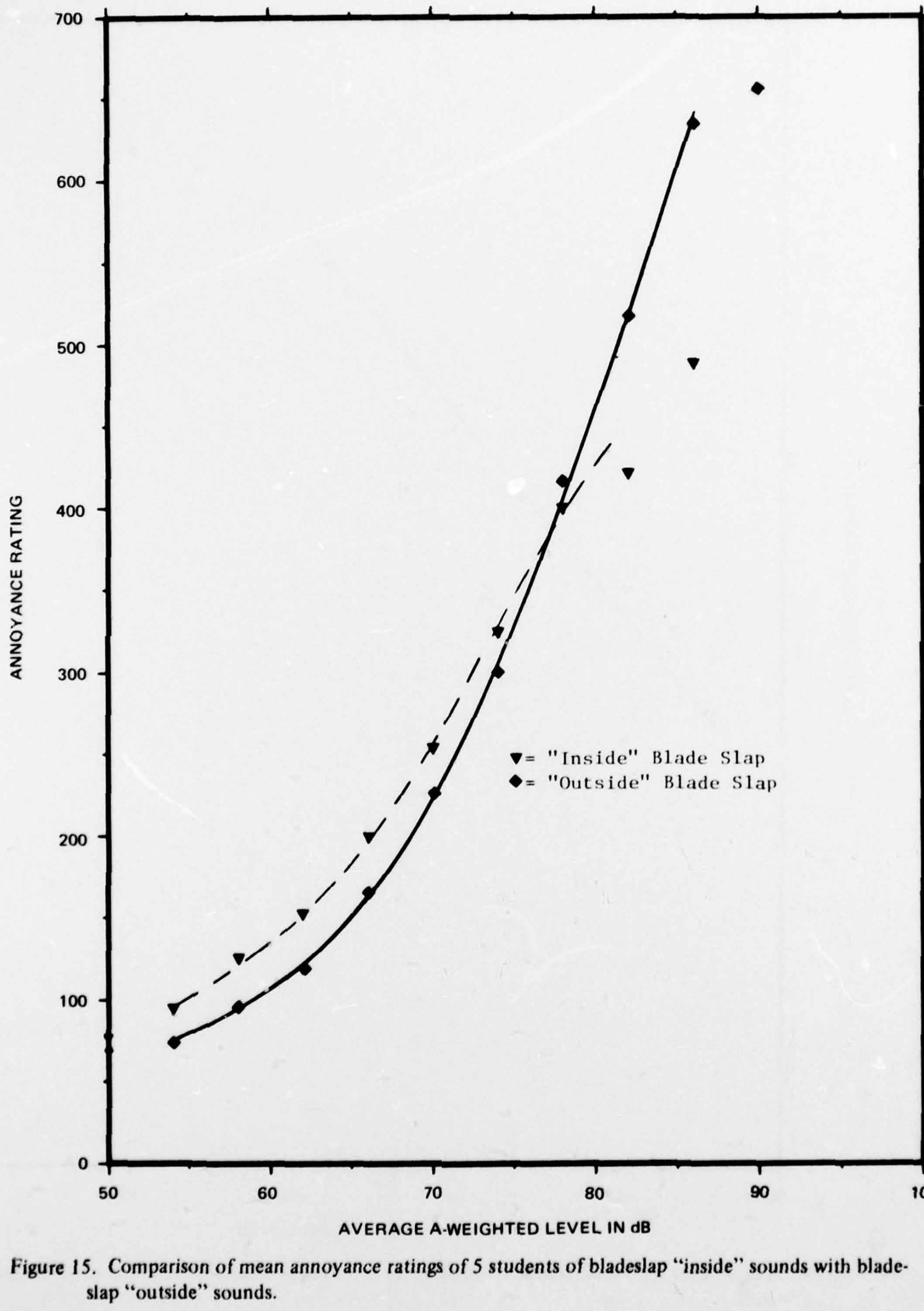

Figure 15. Comparison of mean annoyance ratings of 5 students of bladeslap "inside" sounds with bladeslap "outside" sounds.

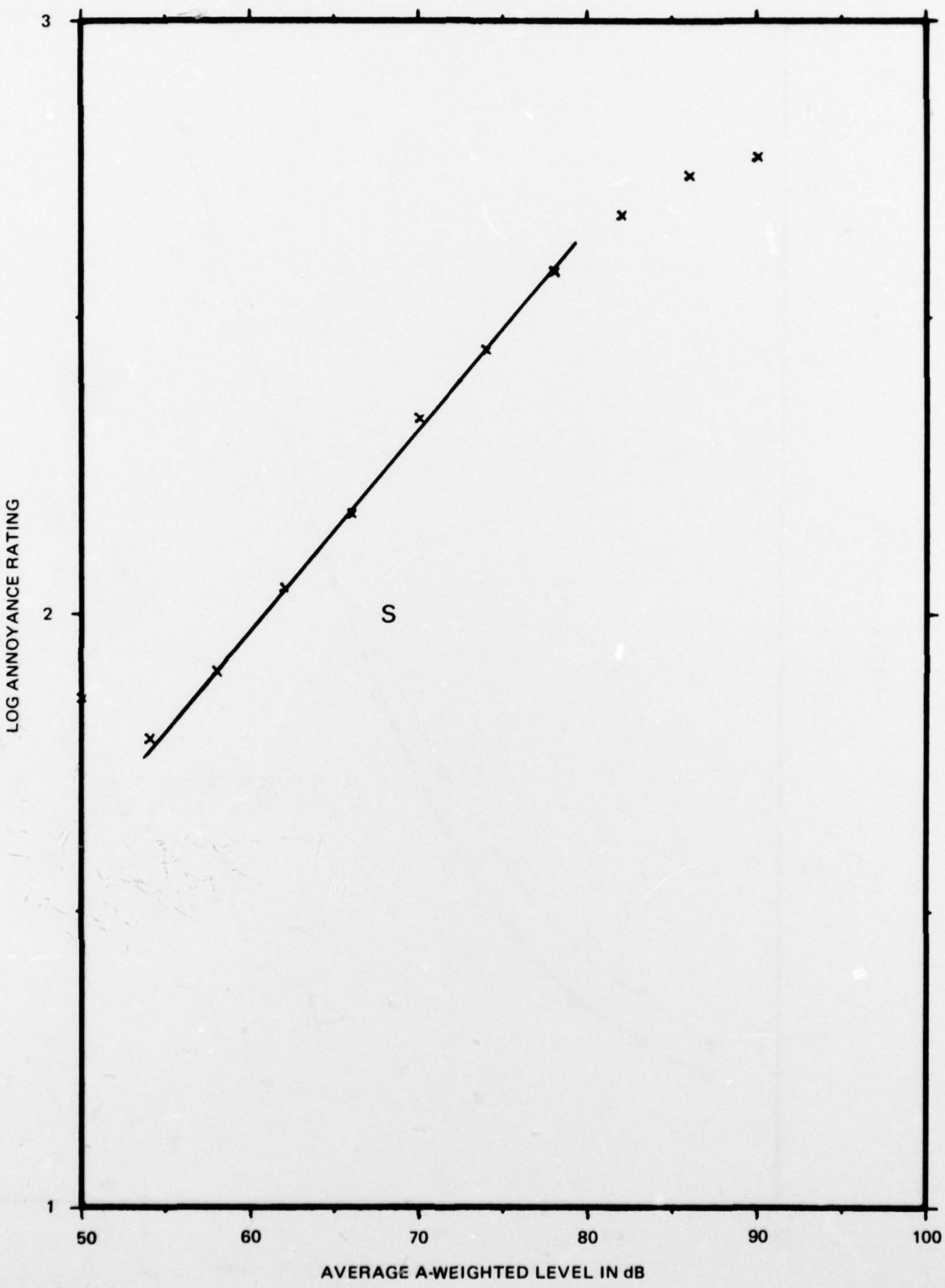

Figure 16. Logarithmic scale presentation of mean annoyance ratings of laboratory group to 35 bladeslap sounds.

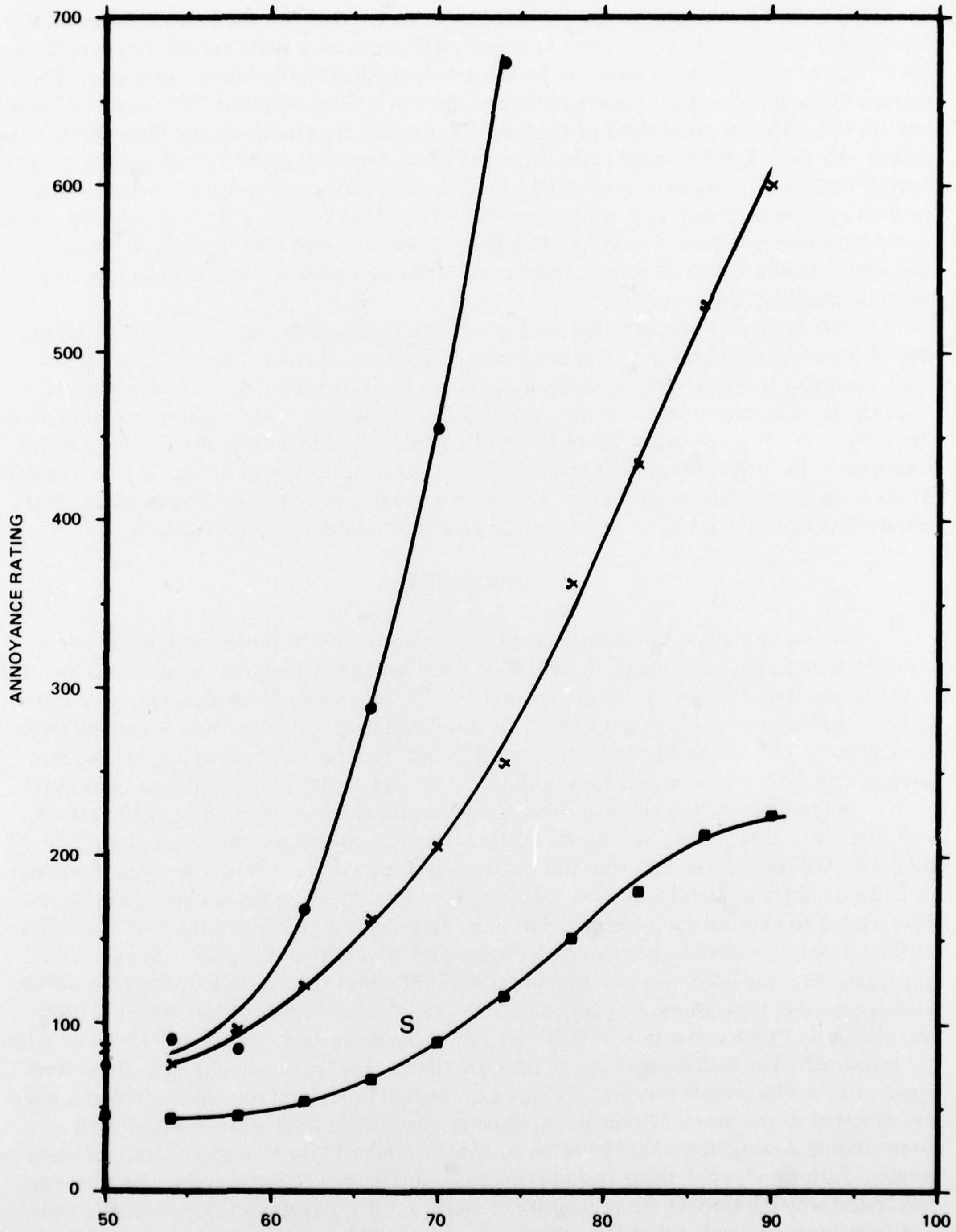

Figure 17. Comparison of mean annoyance ratings of subjects showing highest, median, and lowest responses to 70 helicopter sounds.

annoyance units per dB over a midportion. For this listener, all helicopter noises were more annoying than the standard bus sound. The curve to the right for the listener assigning the lowest annoyance values had a slope of about eight annoyance units per dB; he considered about half of the helicopter noises to be less annoying than the standard bus sound. The listener in the middle of the ranking is represented by a slope of about 20 annoyance units per dB. This listener rated most of the helicopter noises as more annoying than the standard sound. All three listeners were males from the laboratory group and all had normal or near normal hearing. Their annoyance ratings in these helicopter noise tests were closely related to their comments about how noise in general affected them. Thus, the man with the highest annoyance ratings reported loud low frequency noise bothered him appreciably while the man with the lowest annoyance ratings reported that noise did not disturb him very much in everyday life.

Ten students were recruited for the noise tests and all of them completed the first day of instruction and testing. One student indicated that he found the higher level helicopter samples to be extremely disturbing. As the test progressed his number ratings increased. By midpoint of the test he was rating the annoyance of the highest level sounds as "infinity". When it was pointed out to him that there would be difficulty in averaging his responses with those of the other listeners, he defended his ratings as an accurate estimation of his annoyance of the sounds. He declined to serve in any additional test sessions. His results have not been included in any of the graphs or tables in this publication.

DISCUSSION

Samples of helicopter noise with bladeslap were rated as more annoying than samples without bladeslap when presented at equal average A-weighted levels. This inequality was found for two different listener groups, for subgroups of samples chosen for strong bladeslap or for high crest factor, for simulated inside listening, and for sound levels from about 60 to 85 dB(A). Typically, when judged to be equally annoying, helicopter sounds with bladeslap were 2 dB lower in level than helicopter sounds without bladeslap.

Bladeslap has been characterized as a perceptual phenomenon in this publication, with the result that sorting of samples of the helicopter noise has been accomplished by listeners. Galloway[6] has indicated that others have characterized helicopter sounds purely in terms of physical features such as crest factor or level in a frequency band thought to be best related to impulse components. Although agreement is lacking on the best descriptor of the unique impulsive features of helicopter noise, corrections of up to 7 dB have been advocated to compensate for the underestimation of annoyance expected when impulsive helicopter noise is measured in a conventional way[1-2]. The results of the present experiment indicate that a correction of 2 dB need be made when average A-weighted sound levels are measured. The instrument used to measure the average levels was a digital sound level meter with a 64/s sample rate and a 35-ms exponential time constant; these attributes were not essential to the present findings. A visual average sound level as determined with a conventional A-weighted sound level meter with a standard "slow" response gave similar results. Patterson[4], et al, using real helicopter sounds, stated "no correction for bladeslap was found which improves the prediction of annoyance." Lawton[5], using synthetic helicopter sounds, concluded that the annoyance produced by impulsive noise was underestimated by approximately 2 dB. MAN-Acoustics and Noise[3] suggest that "heavy" bladeslap would require a 2-3 dB(A) correction.

To state that helicopter noise with bladeslap requires a 2 dB correction is not the same as saying the day-night average sound level (DNL) or community noise equivalent level (CNEL) measured at an airfield with helicopters should be corrected (increased) by 2 dB. To estimate the effect of a 2 dB bladeslap correction on an adjusted 24 hours average, it is necessary to estimate the amount of time bladeslap is present. Some helicopters produce relatively little bladeslap. Even those which produce strong bladeslap do so only under certain flight conditions and radiate only in certain directions.

Suppose a community location is chosen which has an hourly average sound level of 60 dB(A) during the day, an evening hourly average level of 50 dB(A), and a night hourly average level of 45 dB(A). If 8 hours of non-bladeslap helicopter noise at 70 dB(A) during the day is assumed, the computed DNL and CNEL will be 65.6 dB. If bladeslap were present for two of the daylight hours and a 2 dB correction were applied to the sound levels in those 2 hours, the DNL would become 66.1 dB and the CNEL would become 66.2 – an increase of 0.5 dB and 0.6 dB, respectively. Appendix D lists changes in DNL and CNEL obtained for various amounts of bladeslap and uncorrected noise levels.

For community noise surveys using 24 hour averages, the bladeslap correction will have relatively little effect.

In the range of sound levels from about 60 to 85 dB(A), the relationship between level and annoyance rating was consistent. Outside this region anomalous effects appeared. This could be due to a small number of data samples. At sound levels about 85 dB(A) some listeners considered the sounds quite unpleasant and questioned whether they could make meaningful annoyance ratings. At the lowest levels, some listeners reported they had difficulty in making annoyance ratings since the sounds were really too quiet to annoy them.

In the present experiment, noise rating was an active listening process. Each helicopter sound was attended to closely and was then related to the listener's scale of annoyance. In the community around an airfield, most people do not actively attend to the aircraft sounds and do not attempt to rate them against any kind of standard sound. How these two modes of listening relate, attentive scaled laboratory and inattentive unscaled community, is not known. Reports from those participating in the annoyance rating experiment indicated that the middle level and higher level helicopter sounds would provoke the same response whether at home or at the laboratory. The lower level sounds, it was felt, would be ignored at home during daylight hours; at night such sounds might be judged as more annoying.

It was reassuring to find the laboratory group and the student group producing essentially the same answers in the bladeslap/non-bladeslap comparison. The wider range of age, previous experience with noise, and some high frequency hearing loss in the laboratory group did not appreciably affect the comparison.

The method of magnitude estimation used in this experiment appears to be a suitable choice for rating the annoyance of helicopter sounds. Listeners reported having a feeling of confidence in nearly all judgements, a large number of samples were processed efficiently, and consistent, unambiguous results were obtained.

Helicopter sounds recorded in a residential community undoubtedly differ from those recorded during certification trials. Community sounds would tend toward (1) apparent reduced duration because of ambient noise masking; and (2) diversity because the helicopters sampled range in age from old to new, because pilot flying practices are not

specified, because speed, direction, and height need conform only to standard flight practices, and because weather conditions include such variables as wind, temperature, humidity, etc. For this particular set of samples, a major effect of recording in the community was a frequency weighting imposed by atmospheric transmission and acting to diminish high frequency components. Compared to recordings taken near the helicopter, the more distant community recordings are less rich in detail concerning sounds of gear train, bearings, engine, etc. Bladeslap from the community includes some muffled thuds as well as sharp, high frequency "cracks."

The designation of "heavy bladeslap" should not be taken as being synonymous with "high crest factor" or "no bladeslap" with "low crest factor." It is true that for the 70 samples used in this experiment, all with mean crest factors of 15 and over were classified as either heavy or moderate bladeslap. Similarly, all the samples with mean crest factors equal to or less than 12.5 were in the non-bladeslap group. However, in the category of sounds classified as "heavy bladeslap," three of 15 had mean crest factors less than 13 dB. Thus, 20 percent of the sounds classified as having prominent bladeslap had crest factors associated with ordinary noise. Of the helicopter noises classified as having no bladeslap, five of 35 (14 percent) had crest factors in excess of 15 dB. Although crest factor measurement did permit identification of many of the sounds heard as having bladeslap, it was not a certain method for classification in this experiment.

One of the 10 member student group refused to serve further in additional tests because the helicopter noise was too unpleasant. One of the 19 member laboratory group stated that for the same reason he would not serve as a listener in any additional tests. While the presence or absence of these two people did not change the major conclusions of the subject experiment, such noise sensitive individuals (7 percent of the listeners in the present test) should not be forgotten in relating noise measurements around a Navy airfield to community reactions.

To expedite rapid dissemination of the results of the subject experiment this report has been limited to results using average A-weighted sound levels. Consideration of the effects of other physical measurements and a detailed examination of the physical characteristics of the 70 noise samples will be given in a subsequent report.

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APPENDIX A: LIST OF EQUIPMENT USED IN TESTING

A. Recording equipment:
General Radio P5/P40 microphone/preamplifier with wind screen
Nagra IV-SJ instrumentation recorder

B. Tape duplicating equipment:
Nagra IV-SJ recorder
Revox A-77 recorder (2)

C. Playback equipment:
Revox A-77 recorder
Electronic crossover, 100 Hz
Phase linear 700 amplifier
- driving 2-Cerwin Vega L48E speaker systems

Crown D40 amplifier
driving 2-Altec Lansing A-7 speaker systems

E. Analysis equipment:

Type of analysis	Equipment
A-wt average, A-wt maximum, C-wt average, C-wt maximum	Bolt, Beranek, and Newman Model 614, Configuration 40006, integrating sound level meter, 64 samples/s, 35 ms detector time constant
Peak/RMS	General Radio 1933 sound level meter, A-wt peak, A-wt slow Hewlett-Packard 680 graphic level recorder
One-third octave band levels	General Radio 1933 sound level meter General Radio 1921 real-time analyzer
Narrowband analysis	General Radio 1933 sound level meter Spectral Dynamics SD360 signal spectrum analyzer

APPENDIX B: INSTRUCTIONS TO THOSE TESTED

Your job will be to judge the annoyance of each of a number of helicopter sounds. Here are three examples of the kind of sounds you will be hearing and judging.

(Three helicopter sounds at three different levels presented acoustically.)

Before each group of 10 such helicopter sounds, you will hear what will be called the "standard" or "reference" sound. This sound, a city bus shifting gears and going up a hill, will be the standard against which you will rate the helicopter sounds. Listen now to the standard sound.

(City bus sound, the standard, presented acoustically.)

To judge the annoyance of the helicopter sounds against the standard bus sound refer to the blackboard and use the following arrangement: Call the bus sound "100." If a helicopter sound has the same annoyance as the bus sound, write down 100. Sounds twice as annoying should be called "200," five times as annoying – "500," and 10 times as annoying – "1000." If the helicopter sound is one half as annoying as the bus sound, then call it "50," one quarter as annoying – "25" and one tenth as annoying – "10." Feel free to use numbers as 83 or 1280 if they are needed.

Next will be some practice in using this number rating scheme. Imagine youself at home, outside, reading a newspaper or magazine. In this context listen to the pair of sounds you will hear - first the bus sound (with a value of 100) and then a helicopter sound to which you should mentally assign an annoyance value.

(Bus sound, helicopter sound presented acoustically.)

The number you gave to the helicopter sound may not be the same number your neighbor assigned. Each of you hears the sounds somewhat differently and each is likely to have a different viewpoint about the sounds you will be rating. Are there any questions?

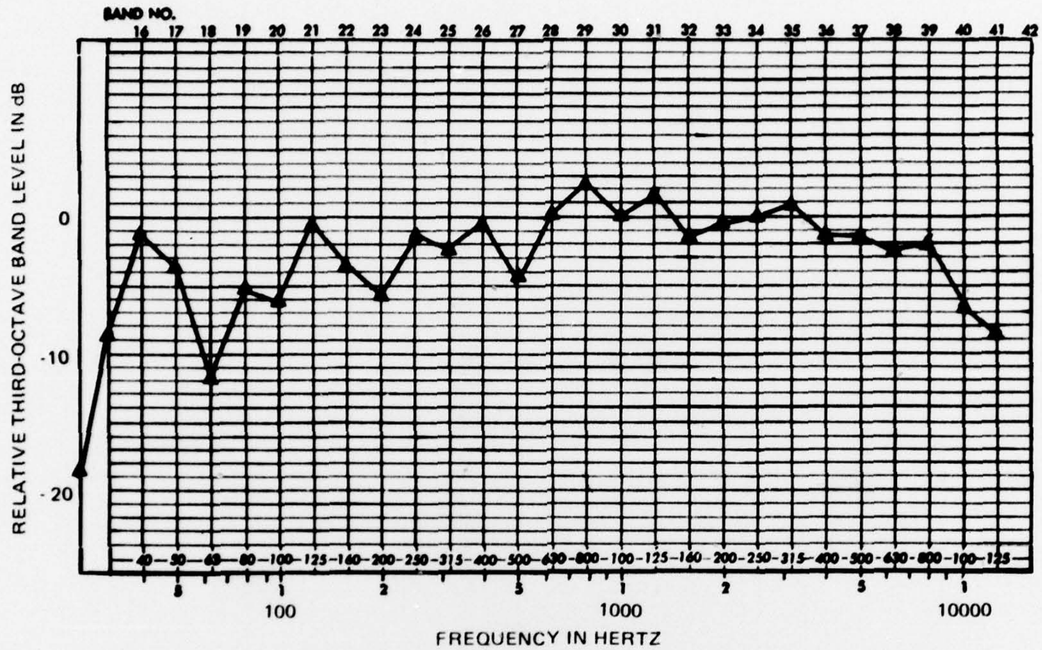
Now a practice tape with five groups of one bus and 10 helicopter sounds will be presented. For these sounds, please write down your answers on the sheet provided. We will rate the first 10 sounds and then stop for any questions you may have. After that the tape will be started again and played through to the end.

(50 helicopter, five bus sounds, practice, presented acoustically.)

Any questions?

Now we will take a short break and then continue through the main test series.

APPENDIX C: RESPONSE OF PLAYBACK SYSTEM



One-third octave acoustic response of playback system in studio with pink noise input.

APPENDIX D: DNL AND CNEL CALCULATIONS WITH AND WITHOUT 2 dB CORRECTION FOR BLADESLAP

Assumptions: Helicopters operating 8 hours/day in daytime only
Helicopters produce 8 hours of 60, 65, 70, and 75 dB sound
Level for daytime when helicopters are not operating is 60 dB
Level in evening is 50 dB; level at night is 45 dB
Helicopters produce bladeslap for one half of 8 hours
Helicopters produce bladeslap for one quarter of 8 hours
Helicopters produce bladeslap for one eighth of 8 hours

Helo Level	Condition	DNL	Change	CNEL	Change
60 dB	No correction	58.0	-	58.2	-
	2 dB correction, 4 hours	58.6	0.6	58.8	0.6
	2 dB correction, 2 hours	58.3	0.3	58.5	0.3
	2 dB correction, 1 hour	58.2	0.2	58.3	0.1
65 dB	No correction	61.3	-	61.4	-
	2 dB correction, 4 hours	62.2	0.9	62.3	0.9
	2 dB correction, 2 hours	61.8	0.5	61.9	0.5
	2 dB correction, 1 hour	61.6	0.3	61.6	0.2
70 dB	No correction	65.6	-	65.6	-
	2 dB correction, 4 hours	66.6	1.0	66.7	1.1
	2 dB ocrrection, 2 hours	66.1	0.5	66.2	0.6
	2 dB correction, 1 hour	65.9	0.3	65.9	0.3
75 dB	No correction	70.3	-	70.4	-
	2 dB correction, 4 hours	71.4	1.1	71.4	1.0
	2 dB correction, 2 hours	70.9	0.6	70.9	0.5
	2 dB correction, 1 hour	70.6	0.3	70.6	0.2